PROCESS PHYSICS: INERTIA, GRAVITY and the QUANTUM*

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Abstract

Process Physics models reality as self-organising relational or semantic information using a self-referentially limited neural network model. This generalises the traditional non-process syntactical modelling of reality by taking account of the limitations and characteristics of self-referential syntactical information systems, discovered by Gödel and Chaitin, and the analogies with the standard quantum formalism and its limitations. In process physics space and quantum physics are emergent and unified, and time is a distinct non-geometric process. Quantum phenomena are caused by fractal topological defects embedded in and forming a growing three-dimensional fractal process-space. Various features of the emergent physics are briefly discussed including: quantum gravity, quantum field theory, limited causality and the Born quantum measurement metarule, inertia, time-dilation effects, gravity and the equivalence principle, a growing universe with a cosmological constant, black holes and event horizons, and the emergence of classicality.

Key words: process physics, Gödel's theorem, neural network, semantic information, self-referential noise, process-time, process-space, quantum gravity.

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1 Introduction

There is mounting evidence that a unification of gravity and quantum theory has finally been achieved, but only after the realisation that the failure to do so, until recently, arose from deep limitations to the traditional modelling of reality by physicists. From its earliest inception physics has modelled reality using formal or syntactical information systems. These have undefined *a priori* entities, such a fields and geometry, together with *a priori* laws. However the actual structure has always been a little messier than that: it is in all cases composed of mathematical equations supplying the core structure, together with metarules that make up for deficiencies of the mathematical model, and finally some metaphysical assertions that usually have an ontological flavour.

A simple early example is actually Newton's geometrical modelling of the phenomena of time. There the mathematical structure is the one-dimensional continuum or geometrical line, but that fails because it has no matching for the present moment effect or even the distinction between past and future. The geometrical-time metarule here involves the notion that one must actively imagine a point moving along a line at a uniform rate, and in this regard the metarule is certainly not inconsistent with the mathematical model. Finally the metaphysical assertion is that time *is* geometrical. Clearly then from the beginning physicists have blurred the three components of modelling.

The ongoing failure of physics to fully match all the aspects of the phenomena of time, apart from that of order, arises because physics has always used non-process models, as is the nature of formal or syntactical systems. Such systems do not require any notion of process - they are entirely structural and static. The new process physics [1, 2, 3, 4] overcomes these deficiencies my using a non-geometric process model for time (see [5] for an early non-technical account), but process physics also argues for the importance of relational or semantic information in modelling reality. Semantic information refers to the notion that reality is a purely informational system where the information is internally meaningful: to be more specific such information has the form of self-organising patterns which also generate their own 'rules of interaction'. In this way we see the correctness of Wheeler's insight of 'Law without Law'[6]. Hence the information is 'content addressable', rather than is the case in the usual syntactical information modelling where the information is represented by symbols. This symbolic or syntactical mode is only applicable to higher level phenomenological descriptions, and has served physics well.

A pure semantic information system must be formed by a subtle bootstrap process. The mathematical model for this has the form of a stochastic neural network (SNN) for the simple reason that neural networks are well known for their pattern or non-symbolic information processing abilities[7]. The stochastic behaviour is related to the limitations of syntactical systems discovered by Gödel[8] and more recently extended by Chaitin[9, 10, 11], but also results in the neural network being innovative in that it creates its own patterns. The neural network is self-referential, and the stochastic input, known as self-referential noise, acts both to limit the depth of the self-referencing and also to generate potential order.

Herein is a status report on the ongoing development of process physics beginning with a discussion of the comparison of syntactical and the new semantic information system and their connections with Gödel's incompleteness theorem. Later sections describe the emergent unification of gravitational and quantum phenomena, amounting to a quantum theory of gravity.

2 Syntactical and Semantic Information Systems

In modelling reality with formal or syntactical information systems physicists assume that the full behaviour of a physical system can be compressed into axioms and rules for the manipulation of symbols. However Gödel discovered that self-referential syntactical systems (and these includes basic mathematics) have fundamental limitations which amount to the realisation that not all truths can be compressed into an axiomatic structure, that formal systems are much weaker than previously supposed. In physics such systems have always been used in conjunction with metarules and metaphysical assertions, all being 'outside' the formal system and designed to overcome the limitations of the syntax. Fig.1 depicts the current understanding of self-referential syntactical systems. Here the key feature is the Gödel boundary demarcating the provable from the unprovable truths of some system. Chaitin has demonstrated that in mathematics the unprovable truths are essentially random in character. This, however, is a structural randomness in the sense that the individual truths do not have any structure to them which could be exploited to condense them down to or be encoded in axioms. This is unlike random physical events which occur in time. Of course syntactical systems are based on the syntax of symbols and this is essentially non-process or non-timelike.

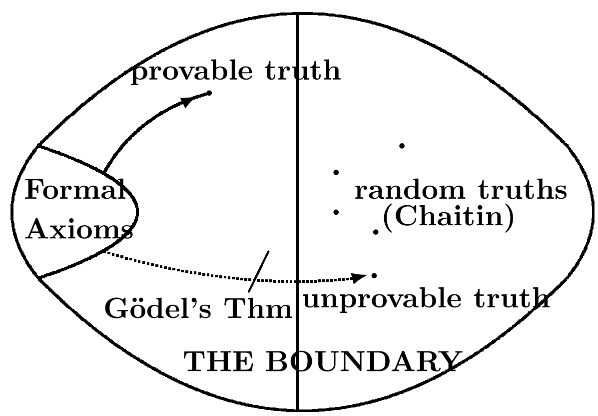


Figure 1: Graphical depiction of the 'logic space' of a self-referential syntactical information system, showing the formal system consisting of symbols and rules, and an example of one theorem (a provable truth). Also shown are unprovable truths which in general are random (or unstructured) in character, following the work of Chaitin. The Gödelian boundary is the demarcation between provable and unprovable truths.

There is an analogy between the structure of self-referential syntactical information systems and the present structure of quantum theory as depicted in Fig.2. There the formal and hence non-process mathematical structure is capable of producing many provable truths, such as the energy levels of the hydrogen atom, and these are also true in the sense that they agree with reality. But from the beginning of quantum theory the Born measurement metarule was introduced to relate this non-process modelling to the actual randomness of quantum measurement events. The individuality of such random events is not a part of the formal structure of quantum theory. Of course it is well known that the non-process or structural aspects of the probability metarule are consistent with the mathematical formalism, in the form of the usual 'conservation of probability' equation and the like. Further, the quantum theory has always been subject to various metaphysical

interpretations, although these have never played a key role for practitioners of the theory. This all suggests that perhaps the Born metarule is bridging a Gödel-type boundary, that there is a bigger system required to fully model quantum aspects of reality, and that the boundary is evidence of self-referencing in that system.

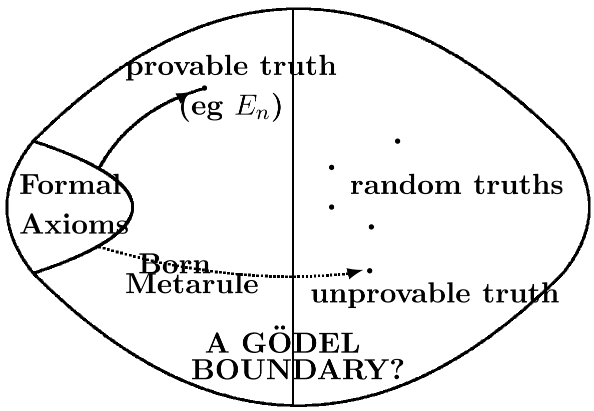


Figure 2: Graphical depiction of the syntactical form of conventional quantum theory. The Born measurement metarule appears to bridge a Gödel-like boundary.

Together the successes and failures of physics suggest that a generalisation of the traditional use of syntactical information theory is required to model reality, and that this has now been identified as a semantic information system which has the form of a stochastic neural network.

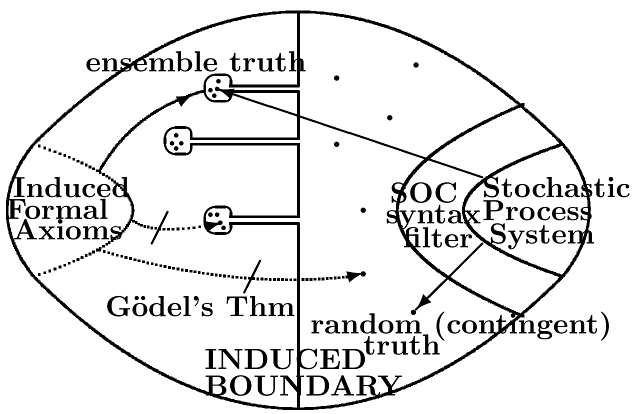


Figure 3: Graphical depiction of the bootstrapping of and the emergent structure of a self-organising pure semantic information system. As a high level effect we see the emergence of an induced formal system, corresponding to the current standard syntactical modelling of reality. There is an emergent Gödel-type boundary which represents the inaccessibility of the random or contingent truths from the induced formal or syntactical system.

Fig.3 shows a graphical depiction of the bootstrapping of a pure semantic information system, showing the stochastic neural network-like process system from which the semantic system is seeded or bootstrapped. Via a Self-Organised Criticality Filter (SOCF) this seeding system is removed or hidden. From the process system, driven by Self-Referential Noise (SRN), there are emergent

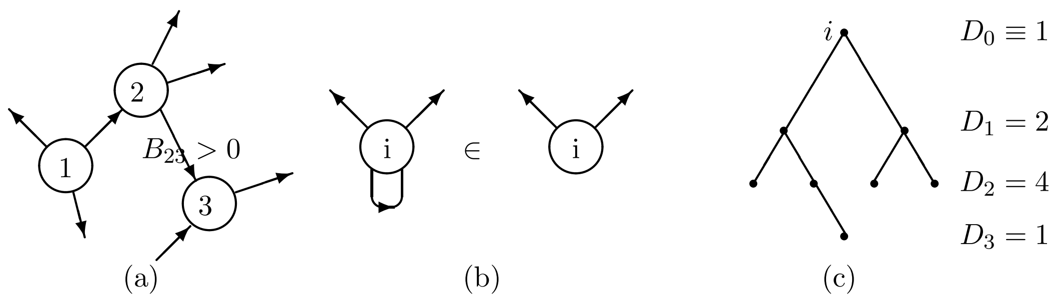


Figure 4: (a) Graphical depiction of the neural network with links $B_{ij} \in \mathcal{R}$ between nodes or pseudo-objects. Arrows indicate sign of B_{ij}. (b) Self-links are internal to a node, so $B_{ii} = 0$. (c) An $N = 8$ spanning tree for a random graph (not shown) with $L = 3$. The distance distribution D_k is indicated for node i.

truths, some of which are generically true (ensemble truths) while others are purely contingent. The ensemble truths are also reachable from the Induced Formal System as theorems, but from which, because of the non-process nature of the induced formal system, the contingent truths cannot be reached. In this manner there arises a Gödel-type boundary. The existence of the latter leads to induced metarules that enhance the induced formal system, if that is to be used solely in higher order phenomenology.

3 Self-Referentially Limited Neural Networks

Here we briefly describe a model for a self-referentially limited neural network and in the following section we describe how such a network results in emergent quantum behaviour, and which, increasingly, appears to be a unification of space and quantum phenomena. Process physics is a semantic information system and is devoid of *a priori* objects and their laws and so it requires a subtle bootstrap mechanism to set it up. We use a stochastic neural network, Fig.4a, having the structure of real-number valued connections or relational information strengths B_{ij} (considered as forming a square matrix) between pairs of nodes or pseudo-objects i and j. In standard neural networks[7] the network information resides in both link and node variables, with the semantic information residing in attractors of the iterative network. Such systems are also not pure in that there is an assumed underlying and manifest *a priori* structure.

The nodes and their link variables will be revealed to be themselves sub-networks of informational relations. To avoid explicit self-connections $B_{ii} \neq 0$, which are a part of the sub-network content of i, we use antisymmetry $B_{ij} = -B_{ji}$ to conveniently ensure that $B_{ii} = 0$, see Fig.4b.

At this stage we are using a syntactical system with symbols B_{ij} and, later, rules for the changes in the values of these variables. This system is the syntactical seed for the pure semantic system. Then to ensure that the nodes and links are not remnant *a priori* objects the system must generate strongly linked nodes (in the sense that the B_{ij} for these nodes are much larger than the B_{ij} values for non- or weakly-linked nodes) forming a fractal network; then self-consistently the start-up nodes and links may themselves be considered as mere names for sub-networks of relations. For a successful suppression the scheme must display self-organised criticality (SOC)[12] which acts as

a filter for the start-up syntax. The designation 'pure' refers to the notion that all seeding syntax has been removed. SOC is the process where the emergent behaviour displays universal criticality in that the behaviour is independent of the individual start-up syntax; such a start-up syntax then has no ontological significance.

To generate a fractal structure we must use a non-linear iterative system for the B_{ij} values. These iterations amount to the necessity to introduce a time-like process. Any system possessing *a priori* 'objects' can never be fundamental as the explanation of such objects must be outside the system. Hence in process physics the absence of intrinsic undefined objects is linked with the phenomena of time, involving as it does an ordering of 'states', the present moment effect, and the distinction between past and present. Conversely in non-process physics the presence of *a priori* objects is related to the use of the non-process geometrical model of time, with this modelling and its geometrical-time metarule being an approximate emergent description from process-time. In this way process physics arrives at a new modelling of time, *process time*, which is much more complex than that introduced by Galileo, developed by Newton, and reaching its high point with Einstein's spacetime geometrical model.

The stochastic neural network so far has been realised with one particular scheme involving a stochastic non-linear matrix iteration, see (1). The matrix inversion B^{-1} then models self-referencing in that it requires all elements of B to compute any one element of B^{-1}. As well there is the additive SRN w_{ij} which limits the self-referential information but, significantly, also acts in such a way that the network is innovative in the sense of generating semantic information, that is information which is internally meaningful. The emergent behaviour is believed to be completely generic in that it is not suggested that reality is a computation, rather it appears that reality has the form of an self-referential order-disorder information system. It is important to note that process physics is a non-reductionist modelling of reality; the basic iterator (1) is premised on the general assumption that reality is sufficiently complex that self-referencing occurs, and that this has limitations. Eqn.(1) is then a minimal bootstrapping implementation of these notions. At higher emergent levels this self-referencing manifests itself as *interactions* between emergent patterns.

To be a successful contender for the Theory of Everything (TOE) process physics must ultimately prove the uniqueness conjecture: that the characteristics (but not the contingent details) of the pure semantic information system are unique. This would involve demonstrating both the effectiveness of the SOC filter and the robustness of the emergent phenomenology, and the complete agreement of the later with observation.

The stochastic neural network is modelled by the iterative process

$$B_{ij} \to B_{ij} - \alpha(B + B^{-1})_{ij} + w_{ij}, \quad i, j = 1, 2, ..., 2M; M \to \infty, \tag{1}$$

where $w_{ij} = -w_{ji}$ are independent random variables for each ij pair and for each iteration and chosen from some probability distribution. Here α is a parameter the precise value of which should not be critical but which influences the self-organisational process. We start the iterator at $B \approx 0$, representing the absence of information. With the noise absent the iterator behaves in a

deterministic and reversible manner given by the matrix

$$B = MDM^{-1}; \qquad D = \begin{pmatrix} 0 & +b_1 & 0 & 0 & & \\ -b_1 & 0 & 0 & 0 & & \\ 0 & 0 & 0 & +b_2 & & \\ 0 & 0 & -b_2 & 0 & & \\ & & & & . & \\ & & & & & . \end{pmatrix}, \qquad b_1, b_2, ... \geq 0, \tag{2}$$

where M is a real orthogonal matrix determined uniquely by the start-up B, and each b_i evolves according to the iterator $b_i \rightarrow b_i - \alpha(b_i - b_i^{-1})$, which converges to $b_i = 1$. This B exhibits no interesting structure. In the presence of the noise the iterator process is non-reversible and non-deterministic. It is also manifestly non-geometric and non-quantum, and so does not assume any of the standard features of syntax based physics models. The dominant mode is the formation of an apparently randomised background (in B_{ij}) but, however, it also manifests a self-organising process which results in a growing three-dimensional fractal process-space that competes with this random background - the formation of a 'bootstrapped universe'. Here we report on the current status of ongoing work to extract the nature of this 'universe'.

The emergence of order in this system might appear to violate expectations regarding the 2nd Law of Thermodynamics; however because of the SRN the system behaves as an open system and the growth of order arises from the self-referencing term, B^{-1} in (1), selecting certain implicit order in the SRN. Hence the SRN acts as a source of negentropy[1]

This growing three-dimensional fractal process-space is an example of a Prigogine far-from-equilibrium dissipative structure[14] driven by the SRN. From each iteration the noise term will additively introduce rare large value w_{ij}. These w_{ij}, which define sets of strongly linked nodes, will persist through more iterations than smaller valued w_{ij} and, as well, they become further linked by the iterator to form a three-dimensional process-space with embedded topological defects. In this way the stochastic neural-network creates stable strange attractors and as well determines their interaction properties. This information is all internal to the system; it is the semantic information within the network.

To see the nature of this internally generated information consider a node i involved in one such large w_{ij}; it will be connected via other large w_{ik} to a number of other nodes and so on, and this whole set of connected nodes forms a connected random graph unit which we call a gebit as it acts as a small piece or bit of geometry formed from random information links and from which the process-space is self-assembled. The gebits compete for new links and undergo mutations. Indeed, as will become clear, process physics is remarkably analogous in its operation to biological systems. The reason for this is becoming clear: both reality and subsystems of reality must use semantic information processing to maintain existence, and symbol manipulating systems are totally unsuited to this need, and in fact totally contrived.

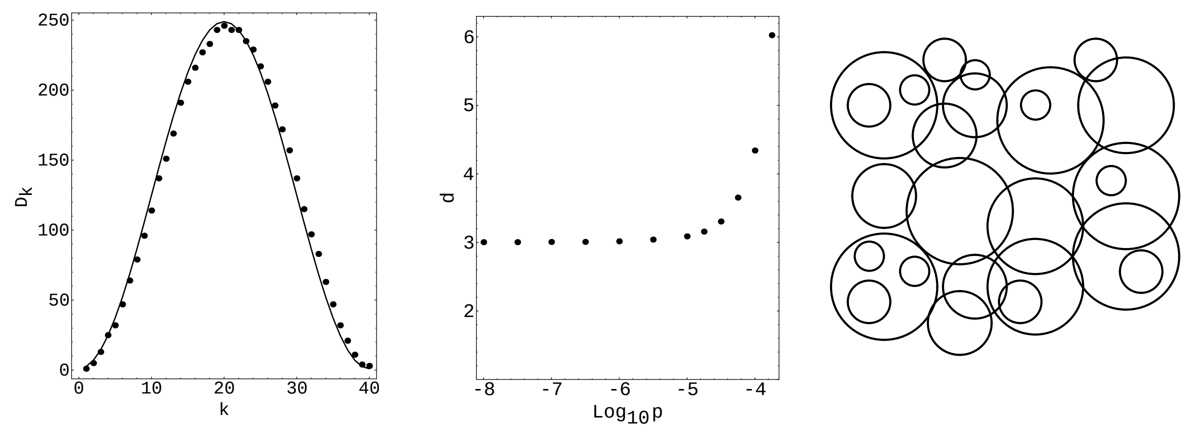
To analyse the connectivity of such gebits assume for simplicity that the large w_{ij} arise with fixed but very small probability p, then the geometry of the gebits is revealed by studying the

[1]The term *negentropy* was introduced by E. Schrödinger[13] in 1945, and since then there has been ongoing discussion of its meaning. In process physics it manifests as the SRN.

probability distribution for the structure of the random graph units or gebits minimal spanning trees with D_k nodes at k links from node i ($D_0 \equiv 1$), see Fig.4c, this is given by[15]

$$\mathcal{P}[D, L, N] \propto \frac{p^{D_1}}{D_1!D_2!....D_L!} \prod_{i=1}^{L-1} (q^{\sum_{j=0}^{i-1} D_j})^{D_{i+1}} (1 - q^{D_i})^{D_{i+1}}, \tag{3}$$

where $q = 1 - p$, N is the total number of nodes in the gebit and L is the maximum depth from node i. To find the most likely connection pattern we numerically maximise $\mathcal{P}[D, L, N]$ for fixed N with respect to L and the D_k. The resulting L and $\{D_1, D_2, ..., D_L\}$ fit very closely to the form $D_k \propto \sin^{d-1}(\pi k/L)$; see Fig.5a for $N = 5000$ and $\mathrm{Log}_{10}p = -6$. The resultant d values for a range of $\mathrm{Log}_{10}p$ and $N = 5000$ are shown in Fig.5b.



(a) (b) (c)

Figure 5: (a) Points show the D_k set and $L = 40$ value found by numerically maximising $\mathcal{P}[D, L, N]$ for $\mathrm{Log}_{10}p = -6$ for fixed $N = 5000$. Curve shows $D_k \propto \sin^{d-1}(\frac{\pi k}{L})$ with best fit $d = 3.16$ and $L = 40$, showing excellent agreement, and indicating embeddability in an S^3 with some topological defects. (b) Dimensionality d of the gebits as a function of the probability p. (c) Graphical depiction of the 'process space' at one stage of the iterative process-time showing a quantum-foam structure formed from embeddings and linkings of gebits. The linkage connections have the distribution of a 3D space, but the individual gebit components are closed compact spaces and cannot be embedded in a 3D background space. So the drawing is only suggestive. Nevertheless this figure indicates that process physics generates a cellular information system, where the behaviour is determined at all levels by internal information.

This shows, for p below a critical value, that $d = 3$, indicating that the connected nodes have a natural embedding in a 3D hypersphere S^3; call this a base gebit. Above that value of p, the increasing value of d indicates the presence of extra links that, while some conform with the embeddability, are in the main defects with respect to the geometry of the S^3. These extra links act as topological defects. By themselves these extra links will have the connectivity and embedding geometry of numbers of gebits, but these gebits have a 'fuzzy' embedding in the base gebit. This is an indication of fuzzy homotopies (a homotopy is, put simply, an embedding of one space into another).

The base gebits $g_1, g_2, ...$ arising from the SRN together with their embedded topological defects

have another remarkable property: they are 'sticky' with respect to the iterator. Consider the larger valued B_{ij} within a given gebit g, they form tree graphs and most tree-graph adjacency matrices are singular ($\det(g_{tree}) = 0$). However the presence of other smaller valued B_{ij} and the general background noise ensures that $\det(g)$ is small but not exactly zero. Then the B matrix has an inverse with large components that act to cross-link the new and existing gebits. This cross-linking is itself random, due to the presence of background noise, and the above analysis may again be used and we would conclude that the base gebits themselves are formed into a 3D hypersphere with embedded topological defects. The nature of the resulting 3D process-space is suggestively indicated in Fig.5c, and behaves essentially as a quantum foam[16].

Over ongoing iterations the existing gebits become cross-linked and eventually lose their ability to undergo further linking; they lose their 'stickiness' and decay. The value of the parameter α in (1) must be small enough that the 'stickiness' persists over many iterations, that is, it is not quenched too quickly, otherwise the emergent network will not grow. Hence the emergent space is 3D but is continually undergoing replacement of its component gebits; it is an informational process-space, in sharp distinction to the non-process continuum geometrical spaces that have played a dominant role in modelling physical space. If the noise is 'turned off' then this emergent dissipative space will decay and cease to exist. We thus see that the nature of space is deeply related to the logic of the limitations of logic, as implemented here as a self-referentially limited neural network.

4 Modelling Gebits and their Topological Defects

We need to extract convenient but approximate syntactical descriptions of the semantic information in the network, and these will have the form of a sequence of mathematical constructions, the first being the Quantum Homotopic Field Theory. Importantly they must all retain explicit manifestations of the SRN. To this end first consider the special case of the iterator when the SRN is frozen at a particular w, that is we consider iterations with an artificially fixed SRN term. Then the iterator is equivalent to the minimisation of an 'energy' expression (remember that B and w are antisymmetric)

$$E[B;w] = -\frac{\alpha}{2}\mathrm{Tr}[B^2] - \alpha\mathrm{TrLn}[B] + \mathrm{Tr}[wB]. \tag{4}$$

Note that for disconnected gebits g_1 and g_2 this energy is additive, $E[g_1 \oplus g_2] = E[g_1] + E[g_2]$. Now suppose the fixed w has the form of a gebit approximating an S^3 network with one embedded topological defect which is itself an S^3 network, for simplicity. So we are dissecting the gebit into base gebit, defect gebit and linkings or embeddings between the two. We also ignore the rest of the network, which is permissible if our gebit is disconnected from it. Now if $\det(w)$ is not small, then this gebit is non-sticky, and for small α, the iterator converges to $B \approx \frac{1}{\alpha}w$, namely an enhancement only of the gebit. However because the gebits are rare constructs they tend to be composed of larger w_{ij} forming tree structures, linked by smaller valued w_{ij}. The tree components make $\det(w)$ smaller, and then the inverse B^{-1} is activated and generates new links. Hence, in particular, the topological defect relaxes, according to the 'energy' measure, with respect to the base gebit. This relaxation is an example of a 'non-linear elastic' process[17]. The above gebit has the form of a mapping $\pi : S \to \Sigma$ from a base space to a target space. Manton[18, 19, 20] has constructed the

continuum form for the 'elastic energy' of such an embedding and for $\pi : S^3 \rightarrow S^3$ it is the Skyrme energy

$$E[U] = \int \left[-\frac{1}{2}\mathrm{Tr}(\partial_i U U^{-1} \partial_i U U^{-1}) - \frac{1}{16}\mathrm{Tr}[\partial_i U U^{-1}, \partial_i U U^{-1}]^2 \right], \tag{5}$$

where $U(x)$ is an element of $SU(2)$. Via the parametrisation $U(x) = \sigma(x) + i\vec{\pi}(x).\vec{\tau}$, where the τ_i are Pauli matrices, we have $\sigma(x)^2 + \vec{\pi}(x)^2{=}1$, which parametrises an S^3 as a unit hypersphere embedded in E^4. Non-trivial minima of $E[U]$ are known as Skyrmions (a form of topological soliton), and have $Z = \pm 1, \pm 2, ...$, where Z is the winding number of the map,

$$Z = \frac{1}{24\pi^2} \int \sum \epsilon_{ijk} \mathrm{Tr}(\partial_i U U^{-1} \partial_j U U^{-1} \partial_k U U^{-1}). \tag{6}$$

The first key to extracting emergent phenomena from the stochastic neural network is the validity of this continuum analogue, namely that $E[B; w]$ and $E[U]$ are describing essentially the same 'energy' reduction process. This should be amenable to detailed analysis.

This 'frozen' SRN analysis of course does not match the time-evolution of the full iterator, (1), for this displays a much richer collection of processes. With ongoing new noise in each iteration and the saturation of the linkage possibilities of the gebits emerging from this noise, there arises a process of ongoing birth, linkaging and then decay of most patterns. The task is then to identify those particular patterns that survive this flux, even though all components of these patterns eventually disappear, and to attempt a description of their modes of behaviour. This brings out the very biological nature of the information processing in the SNN, and which appears to be characteristic of a 'pure' semantic information system.

In general each gebit, as it emerges from the SRN, has active nodes and embedded topological defects, again with active nodes. Further there will be defects embedded in the defects and so on, and so gebits begin to have the appearance of a fractal defect structure, and all the defects having various classifications and associated winding numbers. The energy analogy above suggests that defects with opposite winding numbers at the same fractal depth may annihilate by drifting together and merging. Furthermore the embedding of the defects is unlikely to be 'classical', in the sense of being described by a mapping $\pi(x)$, but rather would be fuzzy, i.e described by some functional, $F[\pi]$, which would correspond to a classical embedding only if F has a supremum at one particular $\pi = \pi_{cl}$. As well these gebits are undergoing linking because their active nodes (see [2] for more discussion) activate the B^{-1} new-links process between them, and so by analogy the gebits themselves form larger structures with embedded fuzzy topological defects. This emergent behaviour is suggestive of a quantum space foam, but one containing topological defects which will be preserved by the system, unless annihilation events occur. If these topological defects are sufficiently rich in fractal structure as to be preserved, then their initial formation would have occurred as the process-space relaxed out of its initial, essentially random form. This phase would correspond to the early stages of the Big-Bang. Once the topological defects are trapped in the process-space they are doomed to meander through that space by essentially self-replicating, i.e. continually having their components die away and be replaced by similar components. These residual topological defects are what we call matter. The behaviour of both the process-space and its defects is clearly determined by the same network processes; we have an essential unification of space and matter phenomena. This emergent quantum foam-like behaviour suggests that the full

generic description of the network behaviour is via the Quantum Homotopic Field Theory (QHFT) of the next section.

5 Modelling the Emergent Quantum Foam

To construct this QHFT we introduce an appropriate configuration space, namely all the possible homotopic mappings $\pi_{\alpha\beta} : S_\beta \to S_\alpha$, where the $S_1, S_2, ..,$ describing 'clean' or topological-defect free gebits, are compact spaces of various types. Then QHFT has the form of an iterative functional Schrödinger equation for the discrete time-evolution of a wave-functional $\Psi[...., \pi_{\alpha\beta}, ...; t]$

$$\Psi[...., \pi_{\alpha\beta}, ...; t + \Delta t] = \Psi[...., \pi_{\alpha\beta}, ...; t] - iH\Psi[...., \pi_{\alpha\beta}, ...; t]\Delta t + \text{QSD terms}, \tag{7}$$

The time step Δt in (7) is relative to the scale of the fractal processes being explicitly described, as we are using a configuration space of mappings between prescribed gebits. At smaller scales we would need a smaller value of Δt. Clearly this invokes a (finite) renormalisation scheme. We now discuss the form of the hamiltonian and the Quantum State Diffusion (QSD) terms.

First (7), without the QSD term, has a form analogous to a 'third quantised' system, in conventional terminology[21]. These systems were considered as perhaps capable of generating a quantum theory of gravity. The argument here is that this is the emergent behaviour of the SNN, and it does indeed lead to quantum gravity, but with quantum matter as well. More importantly we understand the origin of (7), and it will lead to quantum and then classical gravity, rather than arise from classical gravity via some ad hoc or heuristic quantisation procedure.

Depending on the 'peaks' of Ψ and the connectivity of the resultant dominant mappings such mappings are to be interpreted as either embeddings or links; Fig.5c then suggests the dominant process-space form within Ψ showing both links and embeddings. The emergent process-space then has the characteristics of a quantum foam. Note that, as indicated in Fig.5c, the original start-up links and nodes are now absent. Contrary to the suggestion in Fig.5c, this process space cannot be embedded in a *finite* dimensional geometric space with the emergent metric preserved, as it is composed of nested or fractal finite-dimensional closed spaces.

We now consider the form of the hamiltonian H. The previous section suggested that Manton's non-linear elasticity interpretation of the Skyrme energy is appropriate to the SNN. This then suggests that H is the functional operator

$$H = \sum_{\alpha \neq \beta} h[\frac{\delta}{\delta \pi_{\alpha\beta}}, \pi_{\alpha\beta}] \tag{8}$$

where $h[\frac{\delta}{\delta\pi}, \pi]$ is the (quantum) Skyrme Hamiltonian functional operator for the system based on making fuzzy the mappings $\pi : S \to \Sigma$, by having h act on wave-functionals of the form $\Psi[\pi(x); t]$. Then H is the sum of pairwise embedding or homotopy hamiltonians. The corresponding functional Schrödinger equation would simply describe the time evolution of quantised Skyrmions with the base space fixed, and $\Sigma \in SU(2)$. There have been very few analyses of even this class of problem, and then the base space is usually taken to be E^3. We shall not give the explicit form of h as it is complicated, but wait to present the associated action.

In the absence of the QSD terms the time evolution in (7) can be formally written as a functional integral

$$\Psi[\{\pi_{\alpha\beta}\};t'] = \int \prod_{\alpha\neq\beta} \mathcal{D}\tilde{\pi}_{\alpha\beta} e^{iS[\{\tilde{\pi}_{\alpha\beta}\}]}\Psi[\{\pi_{\alpha\beta}\};t], \tag{9}$$

where, using the continuum t limit notation, the action is a sum of pairwise actions,

$$S[\{\tilde{\pi}_{\alpha\beta}\}] = \sum_{\alpha\neq\beta} S_{\alpha\beta}[\tilde{\pi}_{\alpha\beta}], \tag{10}$$

$$S_{\alpha\beta}[\tilde{\pi}] = \int_t^{t'} dt'' \int d^n x\sqrt{-g}\left[\frac{1}{2}\mathrm{Tr}(\partial_\mu \tilde{U}\tilde{U}^{-1}\partial^\mu \tilde{U}\tilde{U}^{-1}) + \frac{1}{16}\mathrm{Tr}[\partial_\mu \tilde{U}\tilde{U}^{-1}, \partial^\nu \tilde{U}\tilde{U}^{-1}]^2\right], \tag{11}$$

and the now time-dependent (indicated by the tilde symbol) mappings $\tilde{\pi}$ are parametrised by $\tilde{U}(x,t)$, $\tilde{U} \in S_\alpha$. The metric $g_{\mu\nu}$ is that of the n-dimensional base space, S_β, in $\pi_{\alpha,\beta} : S_\beta \to S_\alpha$. As usual in the functional integral formalism the functional derivatives in the quantum hamiltonian, in (8), now manifest as the time components ∂_0 in (11), so now (11) has the form of a 'classical' action, and we see the emergence of 'classical' fields, though the emergence of 'classical' behaviour is a more complex process. Eqns.(7) or (9) describe an infinite set of quantum skyrme systems, coupled in a pairwise manner. Note that each homotopic mapping appears in both orders; namely $\pi_{\alpha\beta}$ and $\pi_{\beta\alpha}$.

The Quantum State Diffusion (QSD)[22] terms are non-linear and stochastic,

$$\text{QSD terms} = \sum_\gamma \left(<L_\gamma^\dagger> L_\gamma - \frac{1}{2}L_\gamma^\dagger L_\gamma - <L_\gamma^\dagger><L_\gamma>\right)\Psi\Delta t + \sum_\gamma \left(L_\gamma - <L_\gamma>\right)\Psi\Delta\xi_\gamma, \tag{12}$$

which involves summation over the class of Linblad functional operators L_γ. The QSD terms are up to 5th order in Ψ, as in general,

$$<A>_t = \int \prod_{\alpha\neq\beta} \mathcal{D}\pi_{\alpha\beta}\Psi[\{\pi_{\alpha\beta}\};t]^* A\Psi[\{\pi_{\alpha\beta}\};t] \tag{13}$$

and where $\Delta\xi_\gamma$ are complex statistical variables with means $M(\Delta\xi_\gamma) = 0$, $M(\Delta\xi_\gamma\Delta\xi_{\gamma'}) = 0$ and $M(\Delta\xi_\gamma^*\Delta\xi_{\gamma'}) = \delta(\gamma-\gamma')\Delta t$

These QSD terms are ultimately responsible for the emergence of classicality via an objectification process, but in particular they produce wave-function(al) collapses during quantum measurements, as the QSD terms tend to 'sharpen' the fuzzy homotopies towards classical or sharp homotopies (the forms of the Linblads will be discussed in detail elsewhere). So the QSD terms, as residual SRN effects, lead to the Born quantum measurement random behaviour, but here arising from the process physics, and not being invoked as a metarule. Keeping the QSD terms leads to a functional integral representation for a density matrix formalism in place of (9), and this amounts to a derivation of the decoherence formalism which is usually arrived at by invoking the Born measurement metarule. Here we see that 'decoherence' arises from the limitations on self-referencing.

In the above we have a deterministic and unitary evolution, tracking and preserving topologically encoded information, together with the stochastic QSD terms, whose form protects that information during localisation events, and which also ensures the full matching in QHFT of process-time to

real time: an ordering of events, an intrinsic direction or 'arrow' of time and a modelling of the contingent present moment effect. So we see that process physics generates a complete theory of quantum measurements involving the non-local, non-linear and stochastic QSD terms. It does this because it generates both the 'objectification' process associated with the classical apparatus and the actual process of (partial) wavefunctional collapse as the quantum modes interact with the measuring apparatus. Indeed many of the mysteries of quantum measurement are resolved when it is realised that it is the measuring apparatus itself that actively provokes the collapse, and it does so because the QSD process is most active when the system deviates strongly from its dominant mode, namely the ongoing relaxation of the system to a 3D process-space. This is essentially the process that Penrose[23] suggested, namely that the quantum measurement process is essentially a manifestation of quantum gravity. The demonstration of the validity of the Penrose argument of course could only come about when quantum gravity was *derived* from deeper considerations, and not by some *ad hoc* argument such as the *quantisation* of Einstein's classical spacetime model.

The mappings $\pi_{\alpha\beta}$ are related to group manifold parameter spaces with the group determined by the dynamical stability of the mappings. This symmetry leads to the flavour symmetry of the standard model. Quantum homotopic mappings or skyrmions behave as fermionic or bosonic modes for appropriate winding numbers; so process physics predicts both fermionic and bosonic quantum modes, but with these associated with topologically encoded information and not with objects or 'particles'.

6 Quantum Field Theory

The QHFT is a very complex 'book-keeping' system for the emergent properties of the neural network, and we now sketch how we may extract a more familiar quantum field theory (QFT) that relates to the standard model of 'particle' physics. An effective QHFT should reproduce the emergence of the process-space part of the quantum foam, particularly its 3D aspects. The QSD processes play a key role in this as they tend to enhance classicality. Hence at an appropriate scale QHFT should approximate to a more conventional QFT, namely the emergence of a wavefunctional system $\Psi[U(x);t]$ where the configuration space is that of homotopies from a 3-space to $U(x) \in G$, where G is some group manifold space. This G describes 'flavour' degrees of freedom. Hence the Schrödinger wavefunctional equation for this QFT will have the form

$$\Psi[U;t+\Delta t] = \Psi[U;t] - iH\Psi[U;t]\Delta t + \text{QSD terms}, \tag{14}$$

where the general form of H is known, and where a new residual manifestation of the SRN appears as the QSD terms. This system describes skyrmions embedded in a continuum spacetime. It is significant that such Skyrmions are only stable, at least in flat space and for static skyrmions, if that space is 3D. This tends to confirm the observation that 3D space is special for the neural network process system. Again, in the absence of the QSD terms, we may express (15) in terms of the functional integral

$$\Psi[U;t'] = \int \mathcal{D}\tilde{U} e^{iS[\tilde{U}]}\Psi[U;t]. \tag{15}$$

To gain some insight into the phenomena present in (14) or (15), it is convenient to use the fact that functional integrals of this Skyrmionic form my be written in terms of Grassmann-variable func-

tional integrals, but only by introducing a fictitious 'metacolour' degree of freedom and associated coloured fictitious vector bosons. This is essentially the reverse of the Functional Integral Calculus (FIC) hadronisation technique in the Global Colour Model (GCM) of QCD[24]. The action for the Grassmann and vector boson part of the system is of the form (written for flat spacetime)

$$S[\overline{p}, p, A_\mu^a] = \int d^4x \left(\overline{p}\gamma^\mu(i\partial_\mu + g\frac{\lambda^a}{2}A_\mu^a)p - \frac{1}{4}F_{\mu\nu}^a(A)F^{a\mu\nu}(A) \right), \tag{16}$$

where the Grassmann variables $p_{fc}(x)$ and $\overline{p}_{fc}(x)$ have flavour and metacolour labels. The Skyrmions are then the low energy Nambu-Goldstone modes of this Grassmann system; other emergent modes are of higher energy and can be ignored. These coloured and flavoured but fictitious fermionic fields $\overline{p}$ and p correspond to the proposed preon system[25, 26]. As they are purely fictitious, in the sense that there are no excitations in the system corresponding to them, the metacolour degree of freedom must be hidden or confined. Then while the QHFT and the QFT represent an induced syntax for the semantic information, the preons may be considered as an induced 'alphabet' for that syntax. The advantage of introducing this preon alphabet is that we can more easily determine the states of the system by using the more familiar language of fermions and bosons, rather than working with the skyrmionic system, so long as only colour singlet states are finally permitted. However it is important to note that (16) and the action in (15) are certainly not the final forms. Further analysis will be required to fully extract the induced actions for the emergent QFT.

7 Inertia and Gravity

Process physics predicts that the neural network behaviour will be charactersied by a growing 3-dimensional process-space having, at a large scale, the form of an S^3 hypersphere, which is one of the forms allowed by Einstein's syntactical modelling. It is possible to give the dominant rate of growth of this hypersphere. However first, from random graph theory[27], we expect more than one such spatial system, with each having the character of a growing hypersphere, and all embedded in the random background discussed previously. This background has no metric structure, and so these various hyperspheres have no distance measure over them. We have then a multi-world universe (our 'universe' being merely one of these 'worlds'). Being process spaces they compete for new gebits, and so long as we avoid a saturation case, each will grow according to

$$\frac{dN_i}{dt} = aN_i - bN_i \qquad a > 0, b > 0, \tag{17}$$

where the last term describes the decay of gebits at a rate b, while the first describes growth of the i-th 'world', this being proportional to the size (as measured by its gebit content number) $N_i(t)$ as success in randomly attaching new gebits is proportional to the number of gebits present (the 'stickiness' effect), so long as we ignore the topological defects (quantum 'matter') as these have a different stickiness, and also affect the decay rate, and so slow down the expansion. Thus $N_i(t)$ will show exponential growth, as appears to be the case as indicated by recent observations of very distant supernovae counts[28]. Hence process physics predicts a positive cosmological constant.

One striking outcome of process physics is a possible explanation for the phenomenon of gravity. First note that matter is merely topological defects embedded in the process space, and we expect

such defects to have a larger than usual gebit connectivity; indeed matter is a violation of the 3-D connectivity of this space, and it is for this reason we needed to introduce fields to emulate this extra non-spatial connectivity. One consequence of this is that in the region of these matter fields the gebits decay faster, they are less sticky because of the extra connectivity. Hence in this region, compared to other nearby matter-free regions the gebits are being 'turned over' more frequently but at the same time are less effective in attracting new gebits. Overall this suggests that matter-occupying-regions act as net sinks for gebits, and there will be a trend for the neighbouring process-space to undergo a diffusion/relaxation process in which the space effectively moves towards the matter: matter acts as a sink for space, and never as a source. Such a process would clearly correspond to gravity. As the effect is described by a net diffusion/relaxation of space which acts equally on all surrounding matter, the in-fall mechanism is independent of the nature of the surrounding matter. This is nothing more than Einstein's Equivalence Principle. As well if the in-fall rate exceeds the rate at which 'motion' through the process-space is possible then an event horizon appears, and this is clearly the black hole scenario. Such an event horizon is sufficient condition for the occurrence of Hawking radiation.

Finally we mention one long standing unsolved problem in physics, namely an understanding of inertia. This is the effect where objects continue in uniform motion unless acted upon by 'forces', and was first analysed by Galileo. However there has never been an explanation for this effect; in Newtonian physics it was built into the syntactical description rather than being a prediction of that modelling. Of course current physics is essentially a static modelling of reality, with motion indirectly accessed via the geometrical-time metarule, and so the failure to explain motion is not unexpected. However process physics offers a simple explanation.

The argument for inertia follows from a simple self-consistency argument. Suppose a topological defect, or indeed a vast bound collection of such defects, is indeed 'in motion'. This implies that the gebits are being preferentially replaced in the direction of that 'motion', for motion as such is a self-replication process; there is no mechanism in process physics for a fixed pattern to say 'slide' *through* the process-space. Rather motion is self-replication of the gebit connectivity patterns in a set direction. Since the newest gebits, and hence the stickiest gebits, in each topological defect, are on the side corresponding to the direction of motion, the gebits on that side are preferentially replaced. Hence the motion is self-consistent and self-perpetuating.

An additional effect expected in process physics is that such motion results in a time dilation effect; the self-replication effect is to be considered as partly the self-replication associated with any internal oscillations and partly self-replication associated with 'motion'. This 'competition for resources' results in the slowing down of internal oscillations, an idea discussed by Toffoli[29]. We then see that many of the effects essentially assumed by the formalism of general relativity appear to be emergent phenomena within process physics.

However there is one novel effect that is of some significance. The process-space appears to represent a preferred frame of reference, but one that is well hidden by the time-dilation effects. Hence we would not expect a Michelson-Morley type experiment to reveal this frame. However using the arguments of Hardy[30] we expect that the action of the QSD wavefunctional 'collapse' processes would reveal the proper frame through a multi-component EPR experiment, as the non-local QSD collapse occurs in a truly simultaneous manner; essentially it exposes the underlying global iterations.

8 Conclusions

Sketched out here is the radical proposal that to comprehend reality we need a system richer than mere syntax to capture the notion that reality is at all levels about, what may be called, internal, relational or semantic information, and not, as in the case of syntax, information that is essentially accessible to or characterisable by observers. This necessitates an evolution in modelling reality from a non-process physics to a process physics. Such a development has been long anticipated outside of physics where it is known as *Process Philosophy*[31].

To realise such a system one representation has been proposed and studied, namely that of a self-referentially limited neural-network model, for neural networks are powerful examples of non-symbolic information processing. This neural-network model is manifestly free of any notions of geometry, quantum phenomena or even 'laws of physics'. Nevertheless the arguments presented here strongly suggest that such phenomena are emergent in the neural network but only because the self-referential noise acts as a source of negentropy or order. The model has been developed to the stage where various phenomena have been identified and appropriate induced syntactical descriptions have been suggested. These correspond essentially to the concepts of current physics which, over the years, have been arrived at via increasingly more abstract non-process syntactical modelling. One important addition being the ever-present QSD terms which, as it happens, ensure that the phenomena of time fully matches our experiences of time, and which also plays various other key roles. This new process-physics is inherently non-reductionist as it explicitly assumes that reality is sufficiently complex that it is self-referential, and which may be accessed by using a subtle bootstrap approach. Clearly we see the beginnings of a unification of physics that leads to quantum gravity and classicality and the emergence of syntax and its associated logic of named objects. The confirmation of process physics will involve developing more powerful techniques to facilitate the extraction of the induced syntax for the emergent phenomena. This is a novel and subtle problem.

Process physics also implies that the geometrical construct of spacetime is merely an induced formal system or syntax and does not itself have any ontological status. Nevertheless this syntax is enormously useful for analysing certain technical aspects of reality, so long as we can be sure that the syntax alone does not introduce spurious problems. One well known spurious problem are the divergences in quantum field theory caused by the continuum nature of spacetime. As well it is obvious that we can never discover deeper physics by *quantising* classical systems.

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